Introduction to Noise Parameters

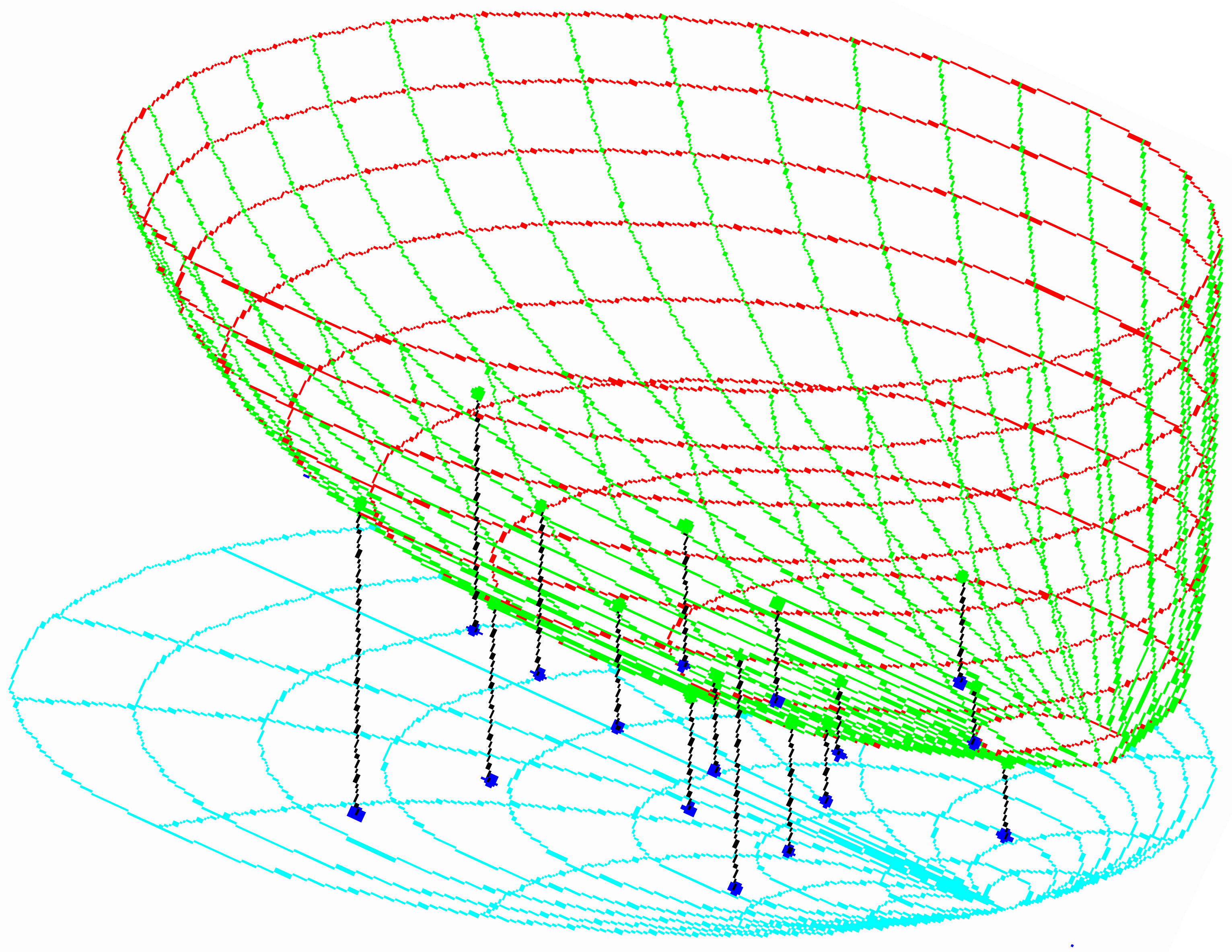
Noise Parameters

Noise Figure:

- Noise Performance at one Impedance
- Typical – 50Ω Noise Figure

Noise Parameters:

- Noise Performance at any Source Impedance



Noise Parameters

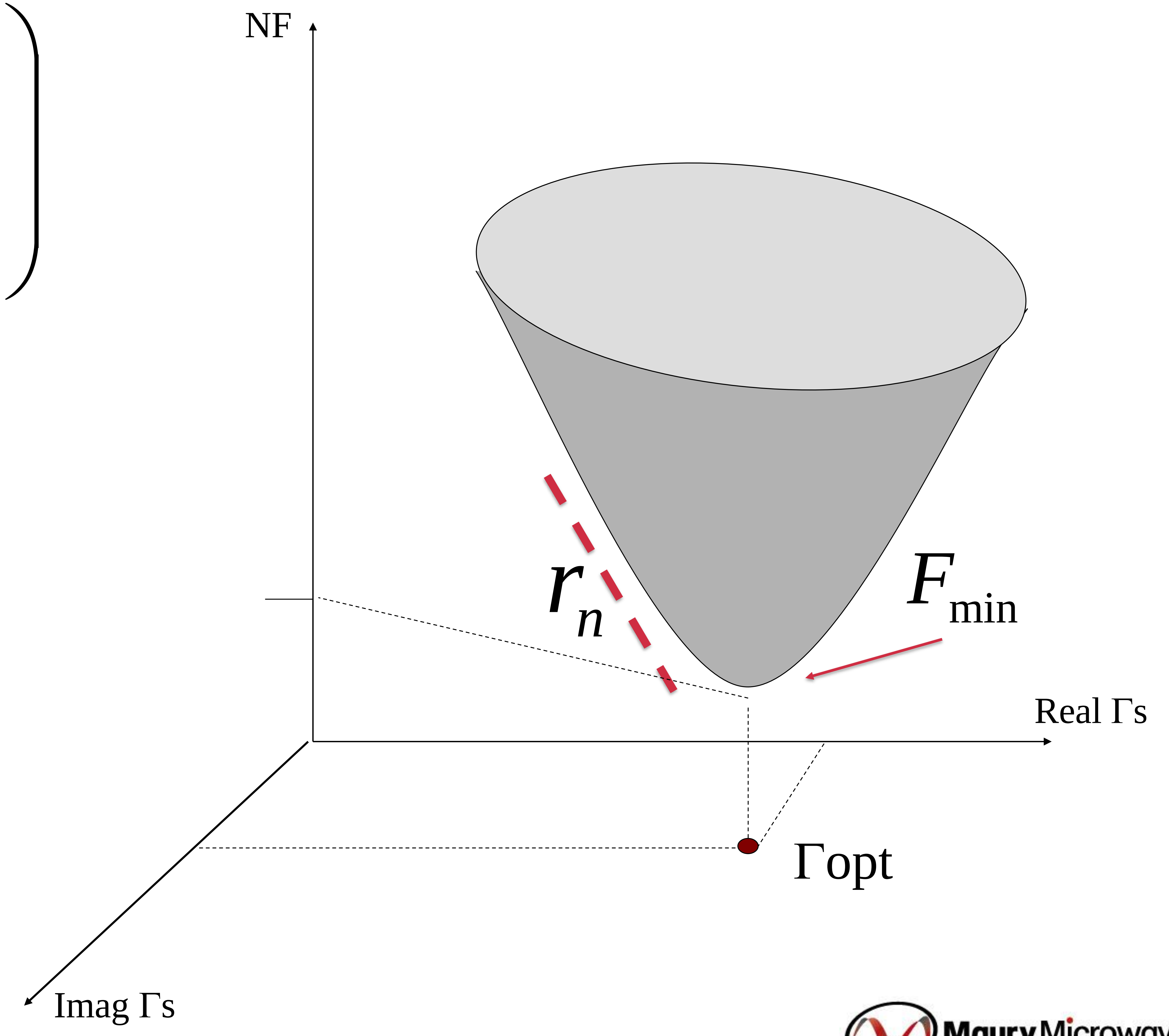
$$F = F_{\min} + 4r_n\left(\frac{\left|\Gamma_s - \Gamma_{opt}\right|^2}{\left|1+\Gamma_{opt}\right|^2\left(1-\left|\Gamma_s\right|\right)^2}\right)$$

Four Scalar Values:

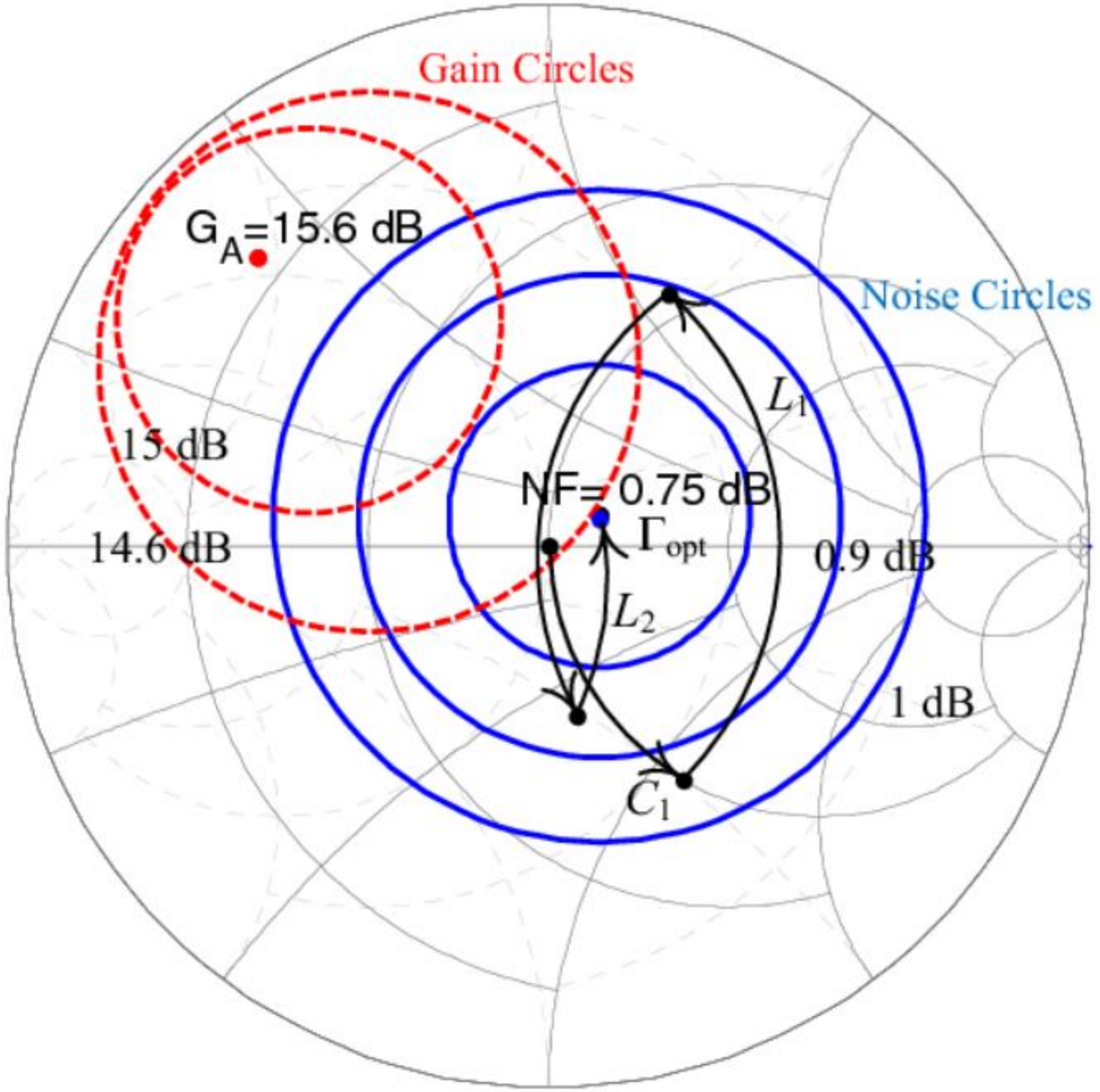
$F_{\min}$

$\Gamma_{opt} \rightarrow |\Gamma_{opt}|, \angle\Gamma_{opt}$

r_n



Noise & Gain Circles



Noise Parameters Measurement

General Method

- Set 4 Values of Γs
- For Each Γs, Measure F
- Solve 4 Simultaneous Equations for the 4 Values

$$F = Fmin + 4r_n \left(\frac{\left|\Gamma_s - \Gamma_{opt}\right|^2}{\left|1 + \Gamma_{opt}\right|^2 (1 - |\Gamma_s|)^2} \right).$$

Noise Parameters Measurement

Practical Method

Use Over-Determined Data:

- Measurement is Sensitive to Small Errors
- Measure at more than 4 Γs Values
- Use Least-Mean-Squares to Reduce Data

Use Noise Power Equation:

- Rigorous Solution
- Account for Γhot and Γcold of Noise Source
- Allows Hot/Cold or Cold Only Approaches

$$P = kB\{[t_{ns} + t_0(F_1 - 1)]G_{A1} + t_0(F_2 - 1)\}G_{T2}$$

Data Collection Methods

Traditional Method

- One Frequency at a Time
- Allows Ideal Impedance Pattern
- Based on 1969 Paper
- Used by everyone for almost 40 years

Very Time Consuming

- Can Have Drift Issues
- Data Scatter

Ultra Fast Method*

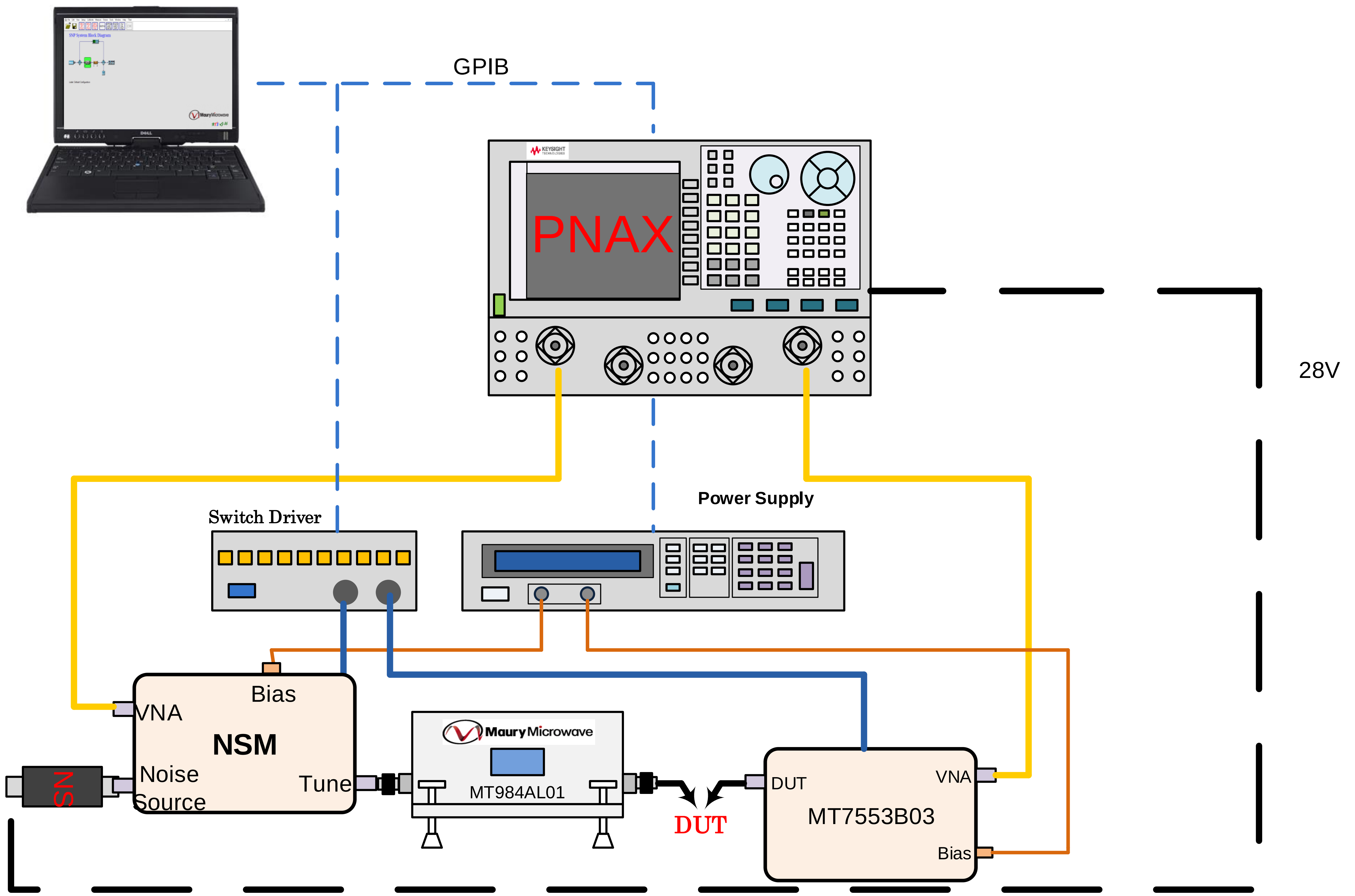
- Characterize One Set Of Tuner States
- Sweep Frequency at Each State
- Take Advantage of Fast Sweep of Modern Instruments

*Invented by Maury Microwave

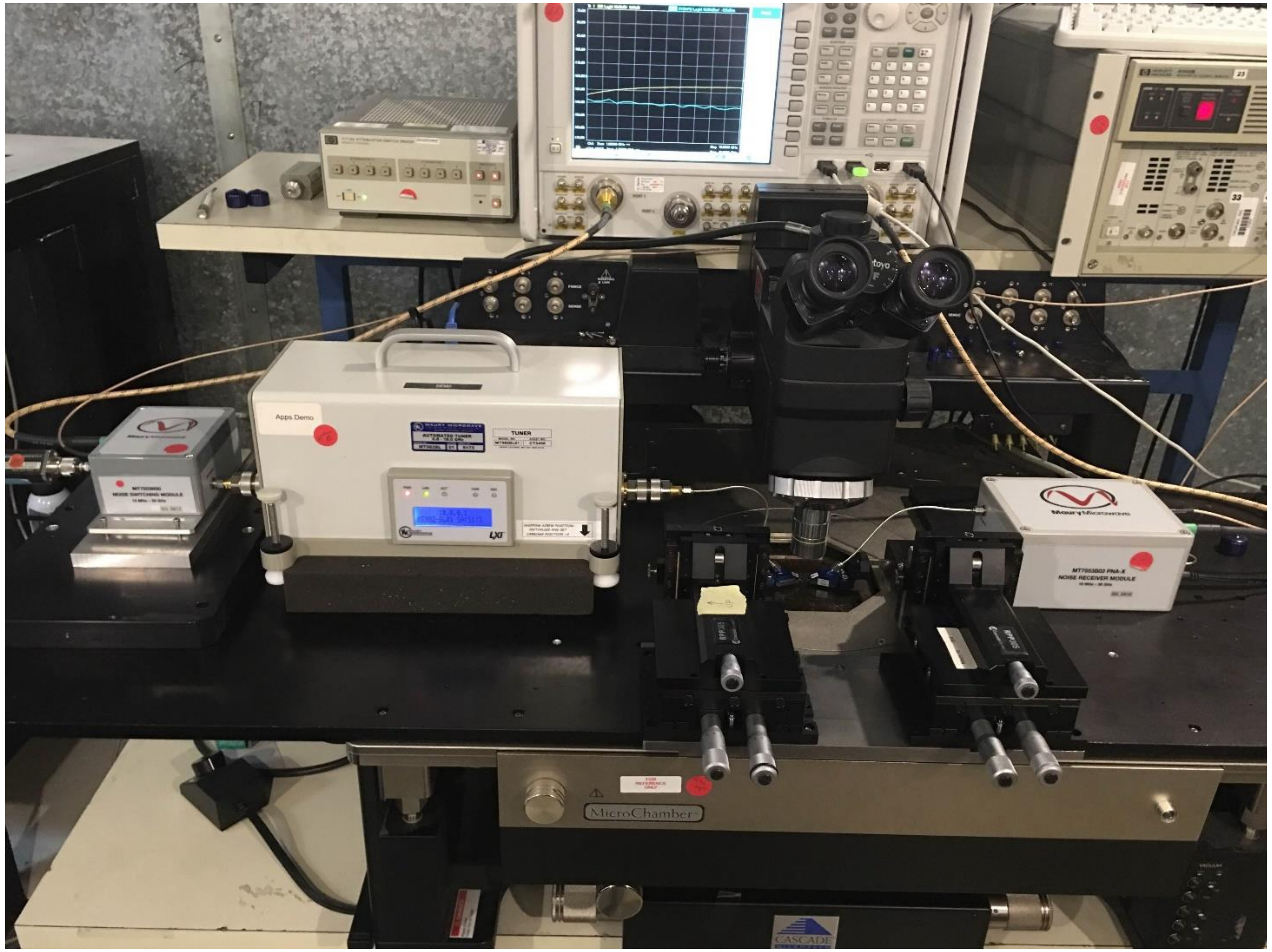
US Patent 8,892,380

Noise Parameters System Block Diagram

Typical Maury on-wafer noise parameters system

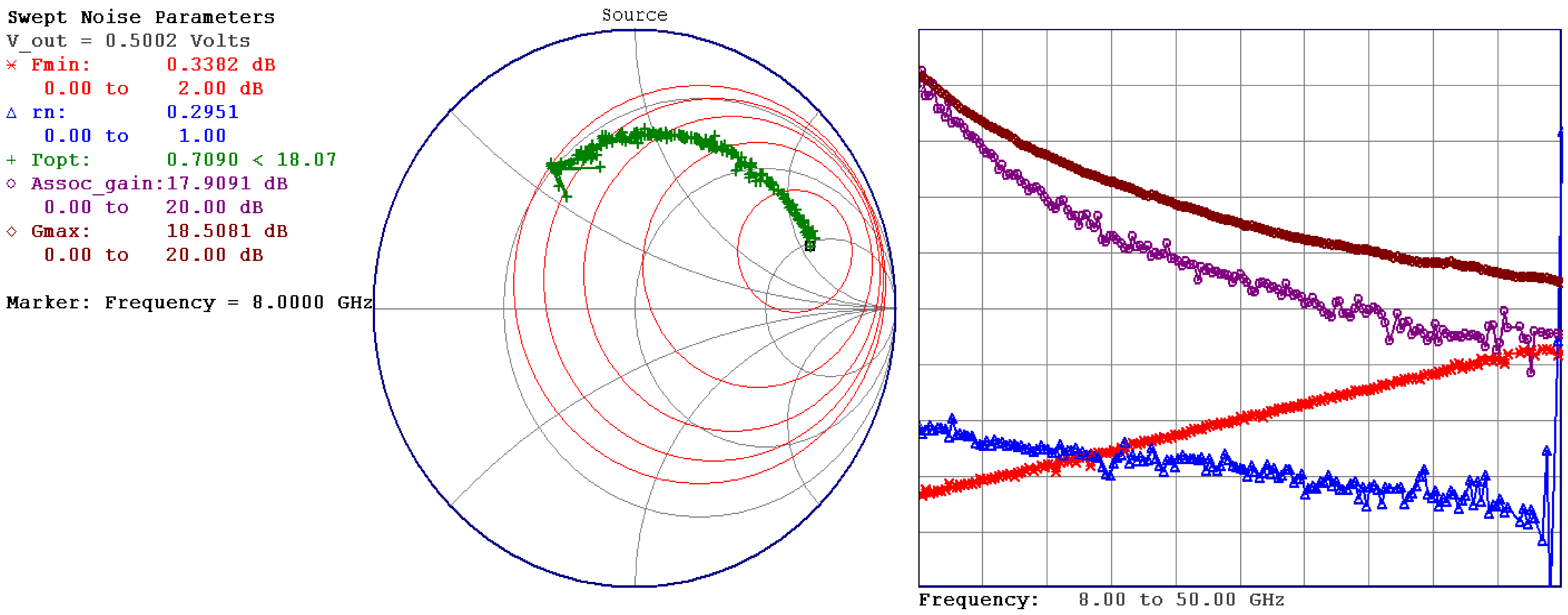


Noise Parameters System Photo



Noise Parameters Measurement Results

On-Wafer, 8-50 GHz, Fmin= 0.35 – 0.9 dB



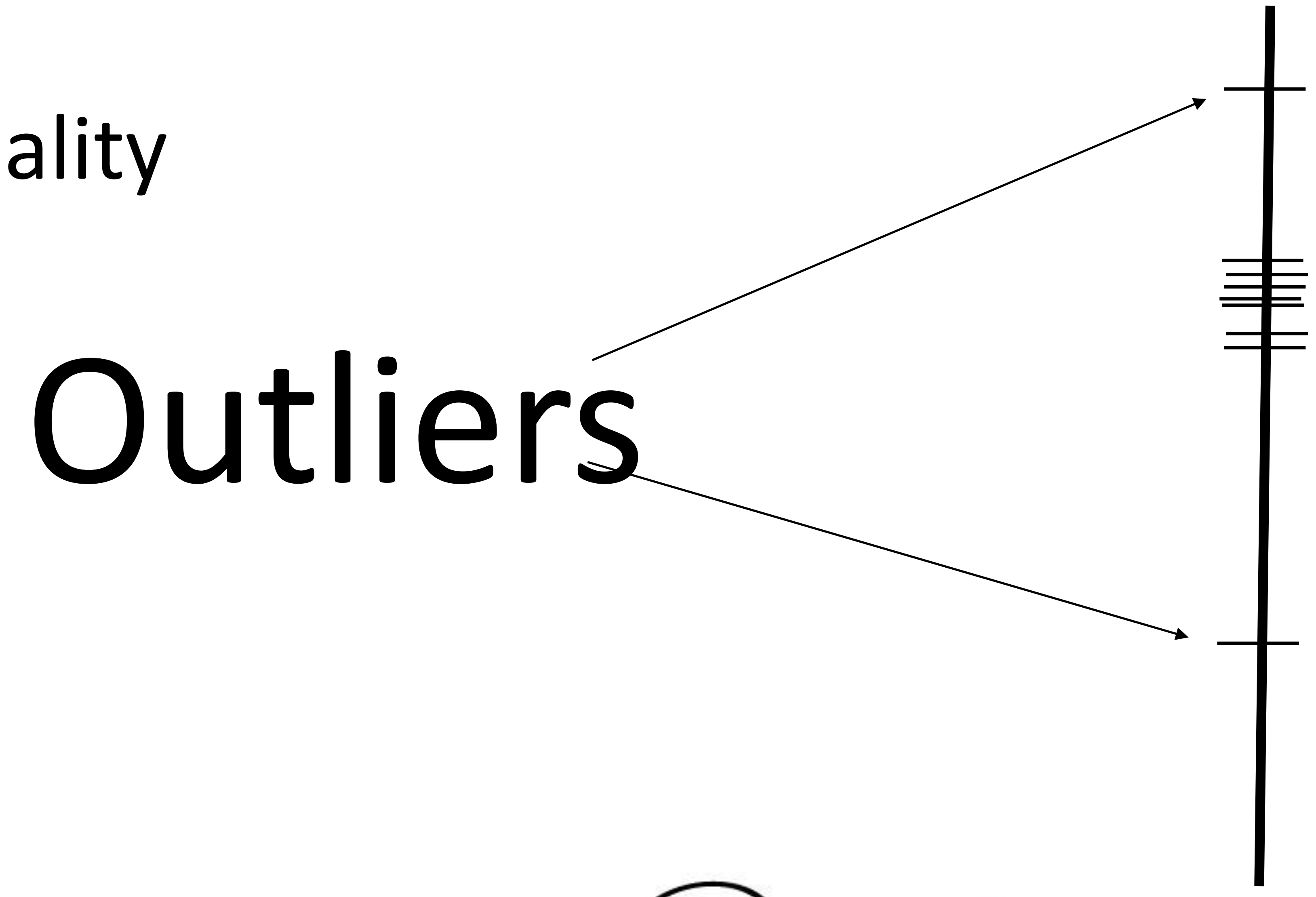
Measured Data, No Smoothing Applied

Data Outliers and Noise Data Processing

- Transistor Data should be continuous
- Noise Measurements are Over-Determined
- Noise Data results should always come from one set of measured data.

Processing:

- Data Outlier causes change from good data
- Calculate Noise Parameters from Subsets to Remove Outliers
- Errors add or cancel at different frequencies
- Data Scatter vs Frequency is an Indicator of the measurement quality
- Removing outliers tends to reduce scatter



Noise Parameter Validation & Confidence in Measurements

Measurement Confidence

System Accuracy is established using known devices:

- Passive Verification Devices
- Active Device as Golden Standard
- Cascade Verification

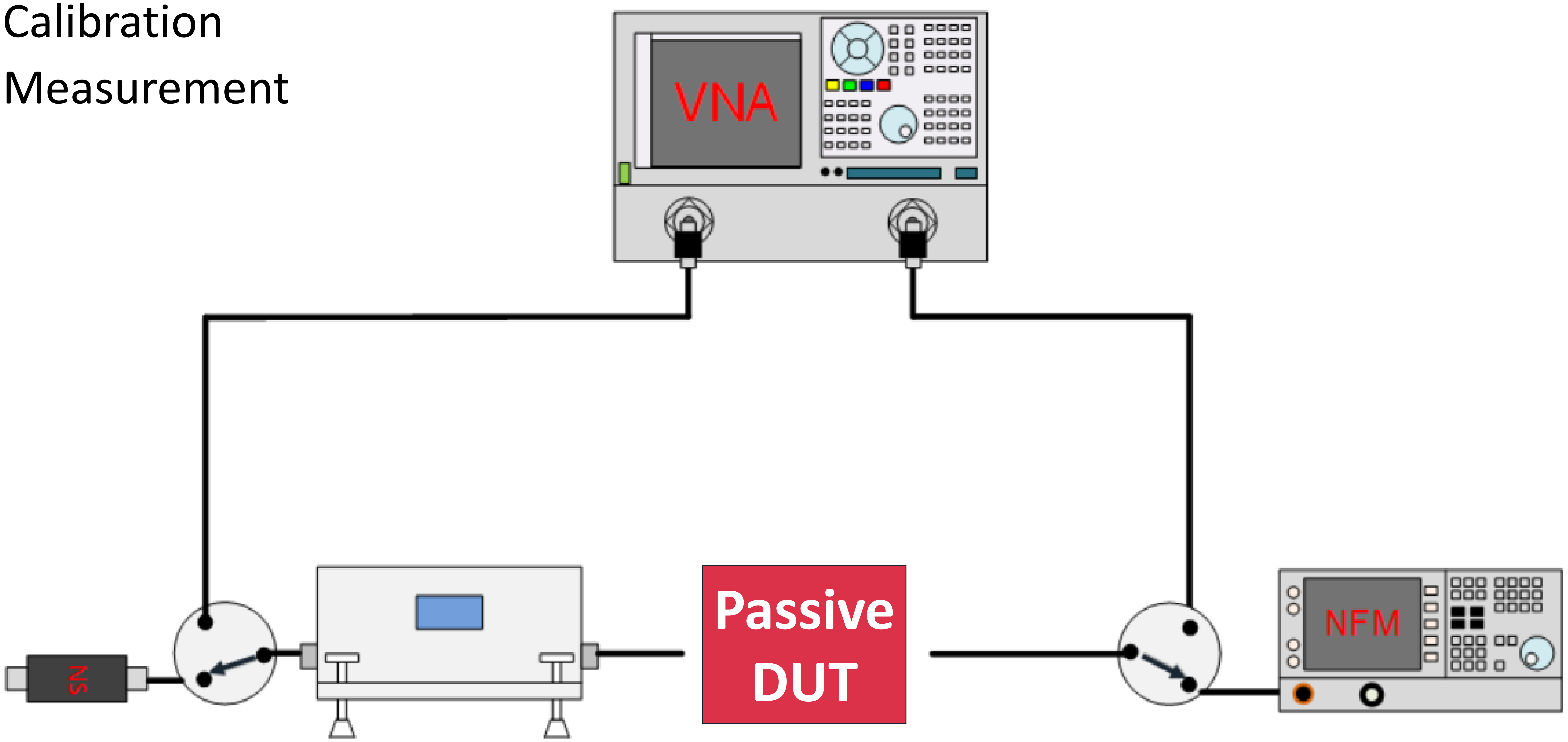
System Repeatability must be a requirement

- Measurement Repeatability
  - Multiple calibrations
  - Overlap bands with different tuners or receivers
  - Comparison with other Labs
- Benchmark with legacy ATN systems

Passive Device Measurement

A passive device tests accuracy of:

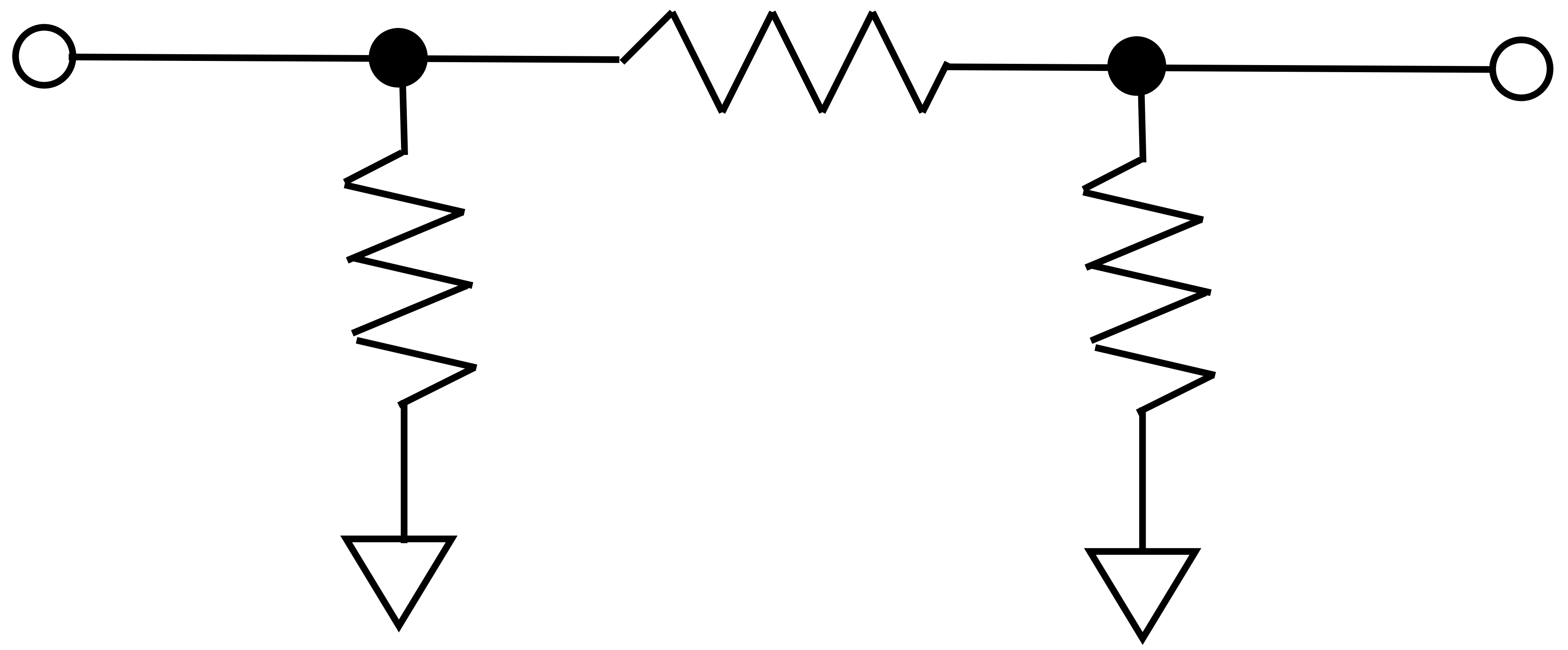
- S-Parameter Measurements
- Noise Calibration
- Noise Measurement



Passive Device Measurement

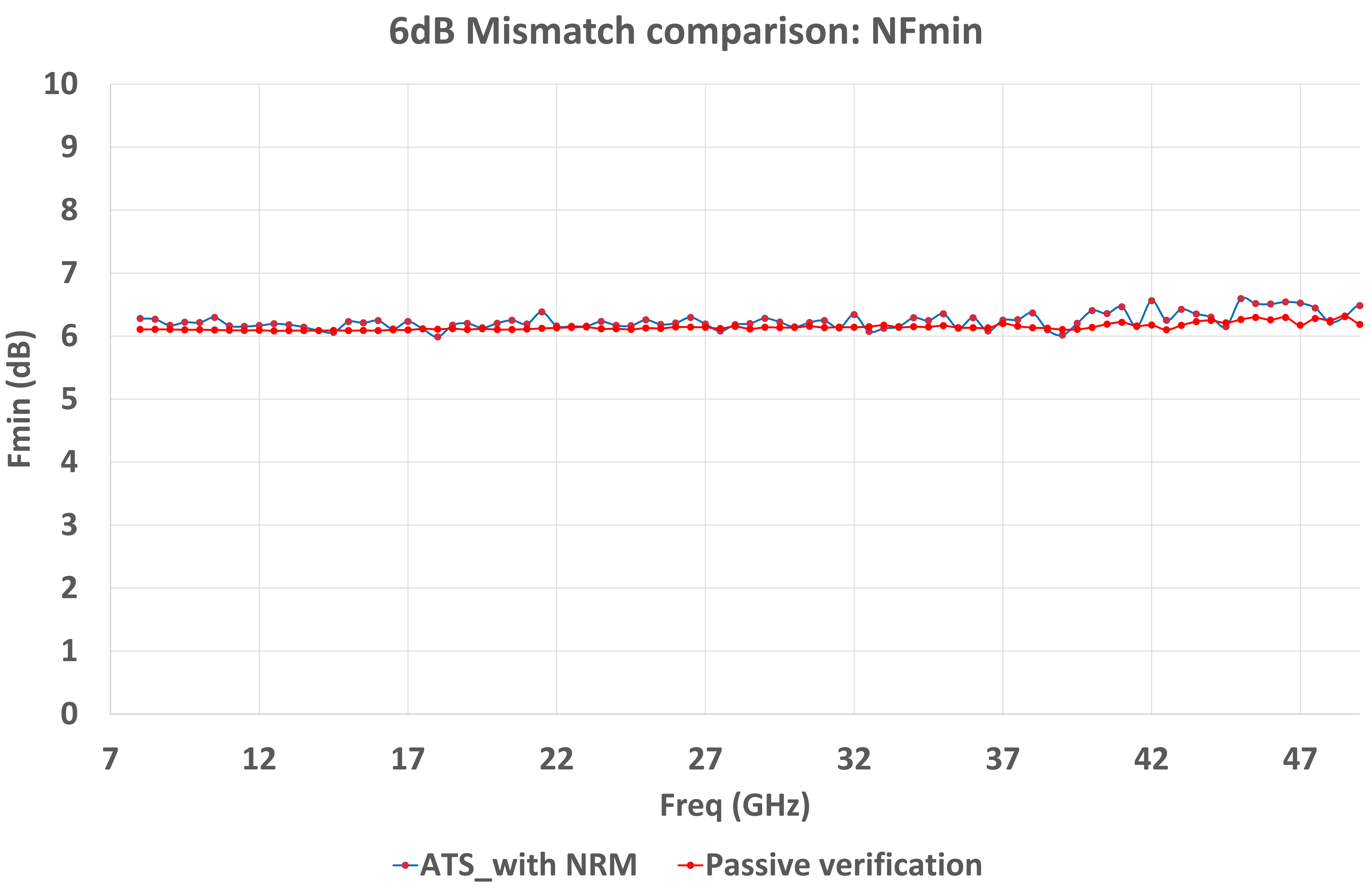
Two Options:

- Matched Passive Device → Some Errors are Masked
- Mismatched Passive Device → Better Test



Known Limitation: System is tested at a different Gain Range than Active DUT

Passive Device Measurement

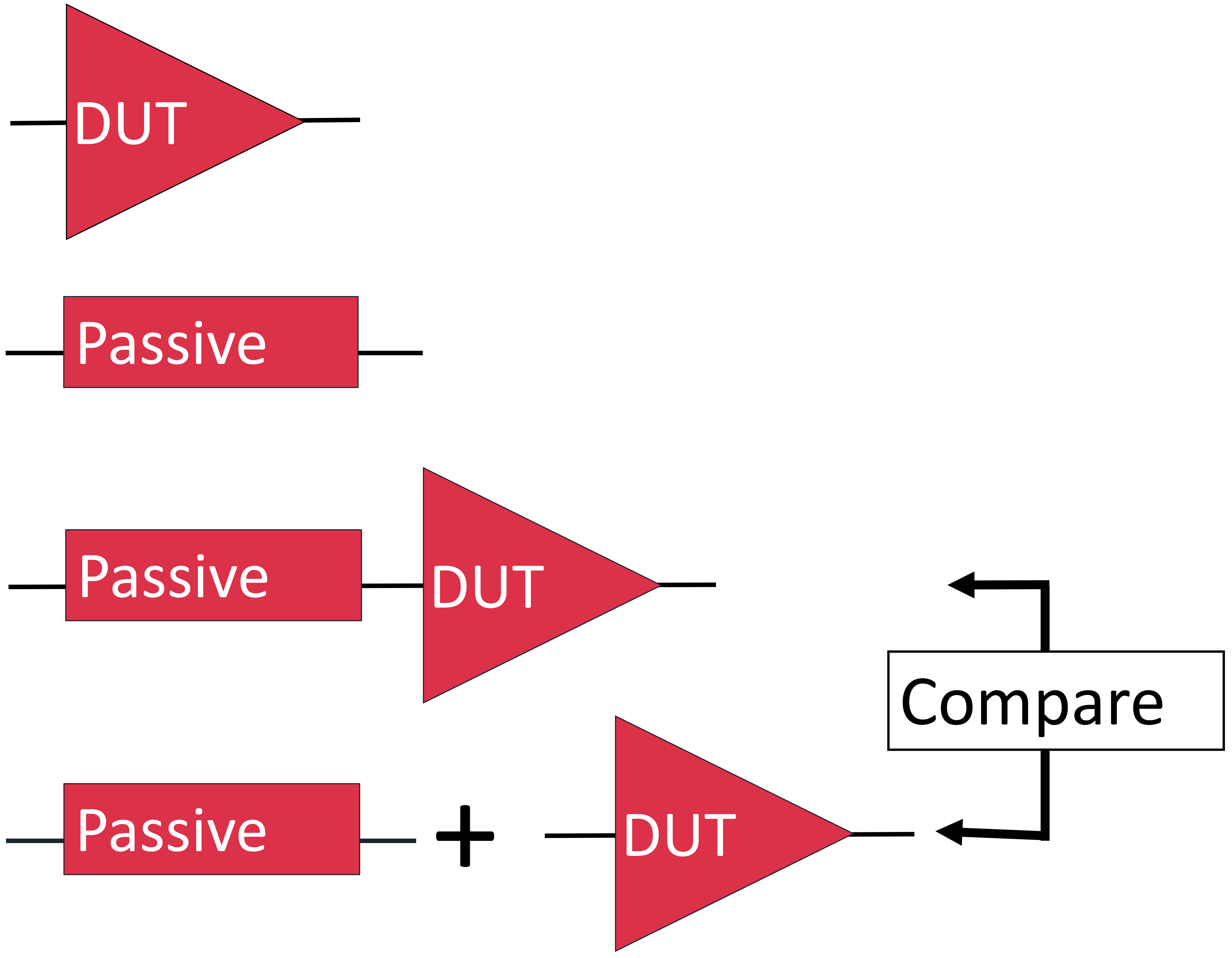


Active Device as Golden Standard

- Challenges:
  - Selecting a stable bias condition for repeatable measurements
  - Device wears out over multiple touch-downs
  - Device performance can change over time
- Benefits:
  - System verification is established using similar DUT conditions
- Recommendations:
  - Multiple known devices based on reference measurements
  - Limit the usage of these golden standards to system verification only

Cascade Verification

1. Measure Noise
2. Measure S-Para
3. Measure Noise
4. Calculate Noise



Advantage: System is tested at same Gain Range as Active DUT

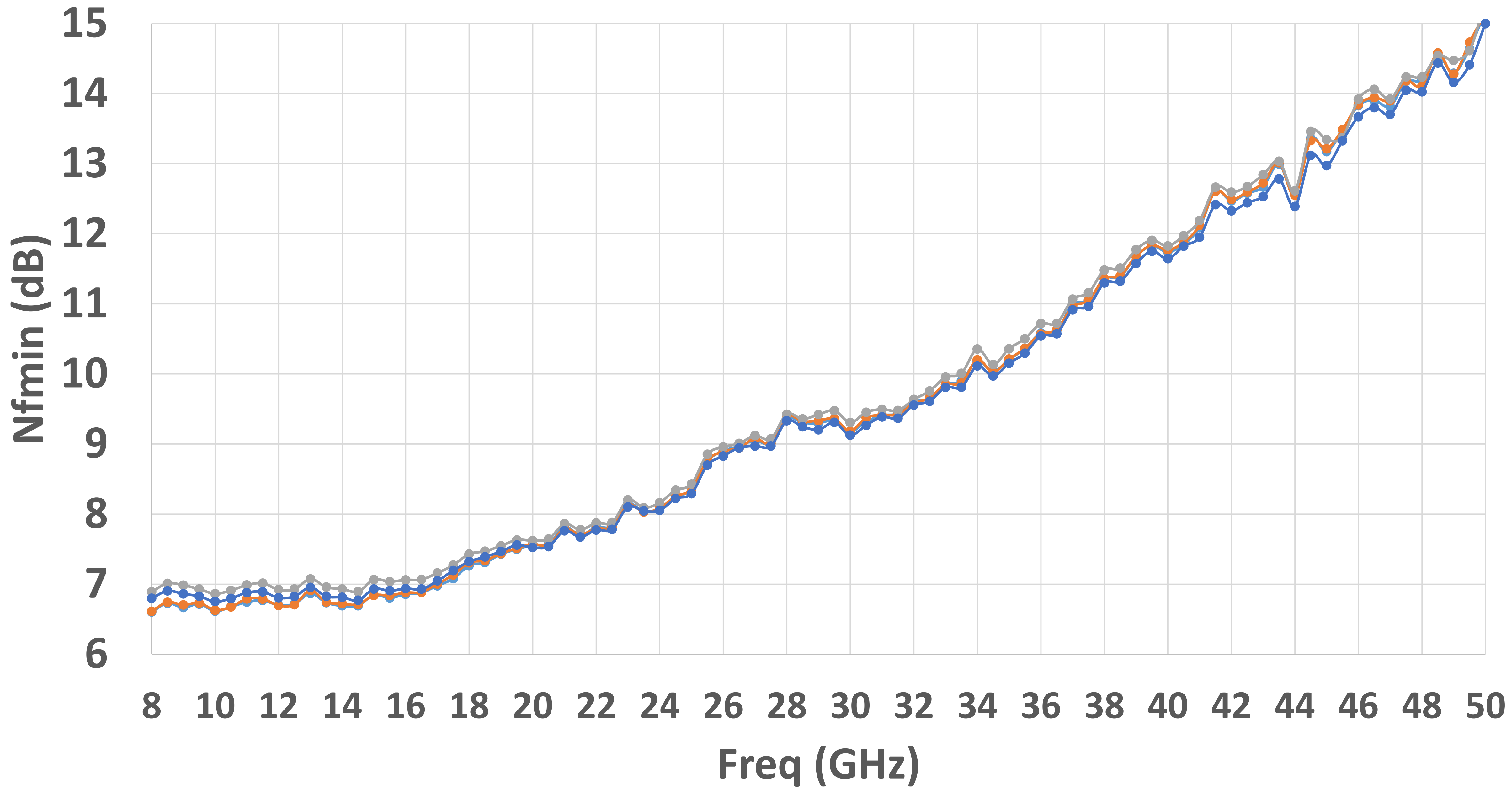
System Repeatability

- Measurement Repeatability
  - S-parameters
  - Multiple calibrations
  - Overlapping bands with different tuners (same or different setups)
  - Comparison between measurements at different sites
- Benchmark with legacy ATN system

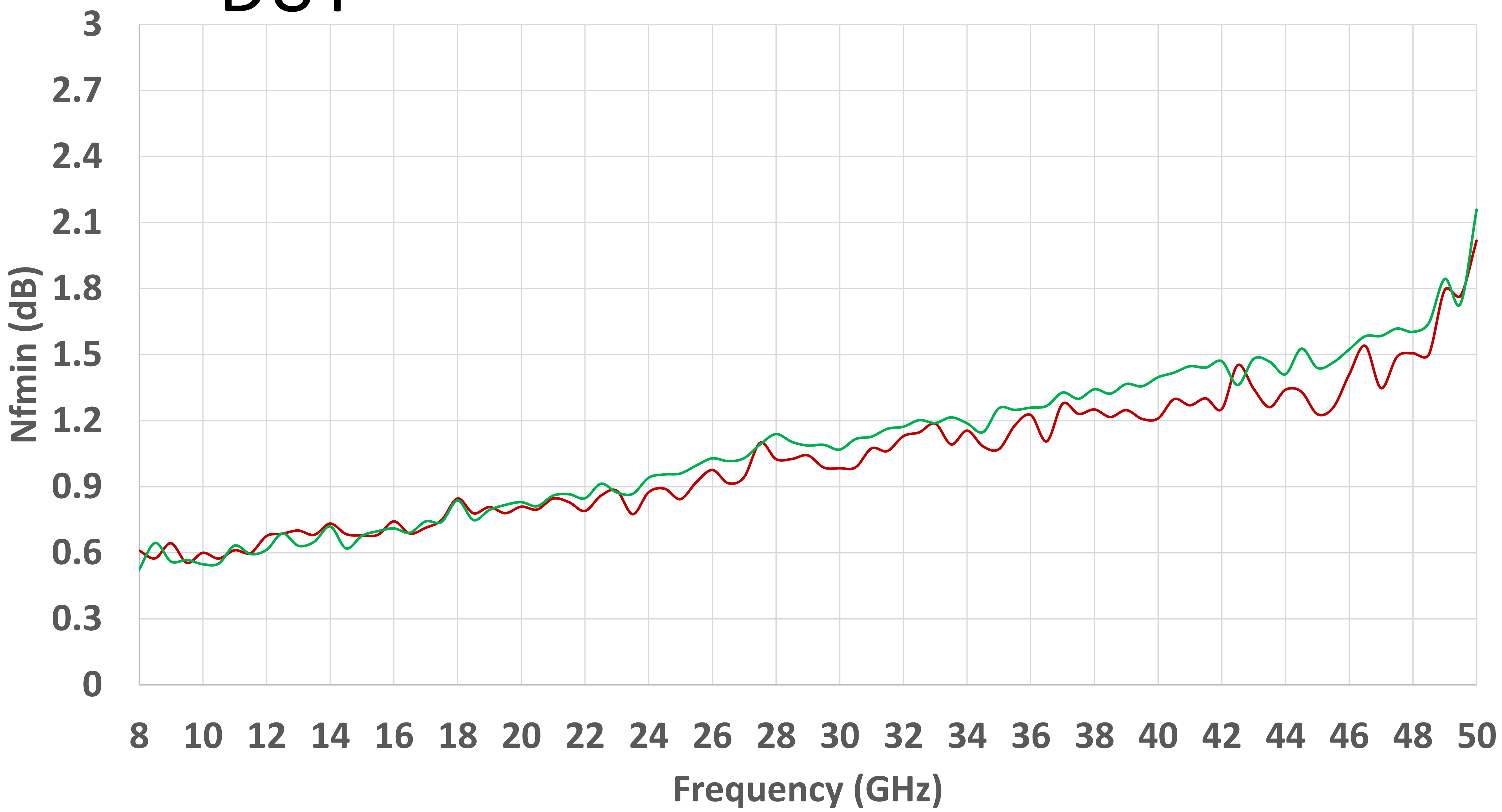
Noise Measurement Repeatability

RAW DATA

Noise Calibration

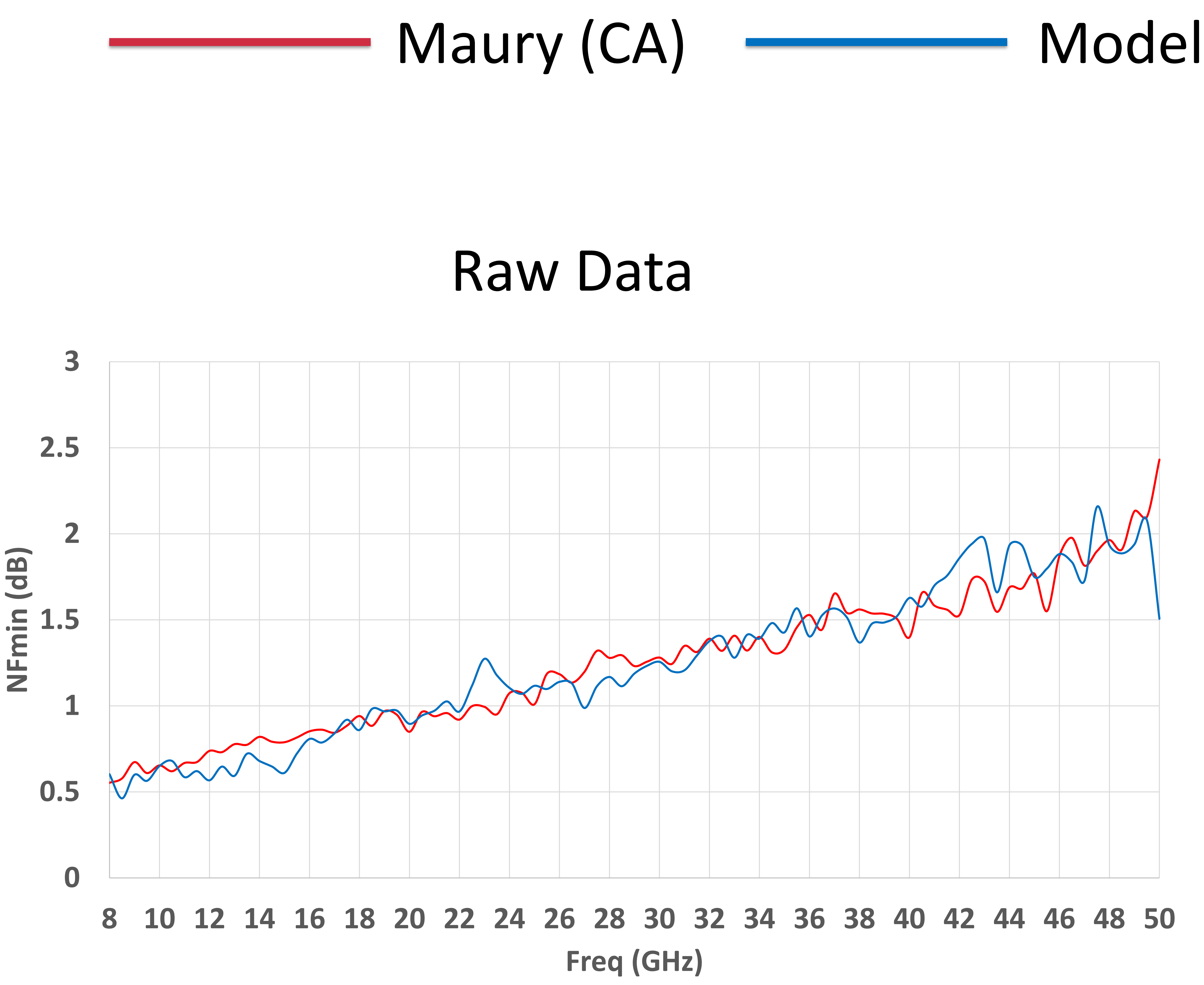


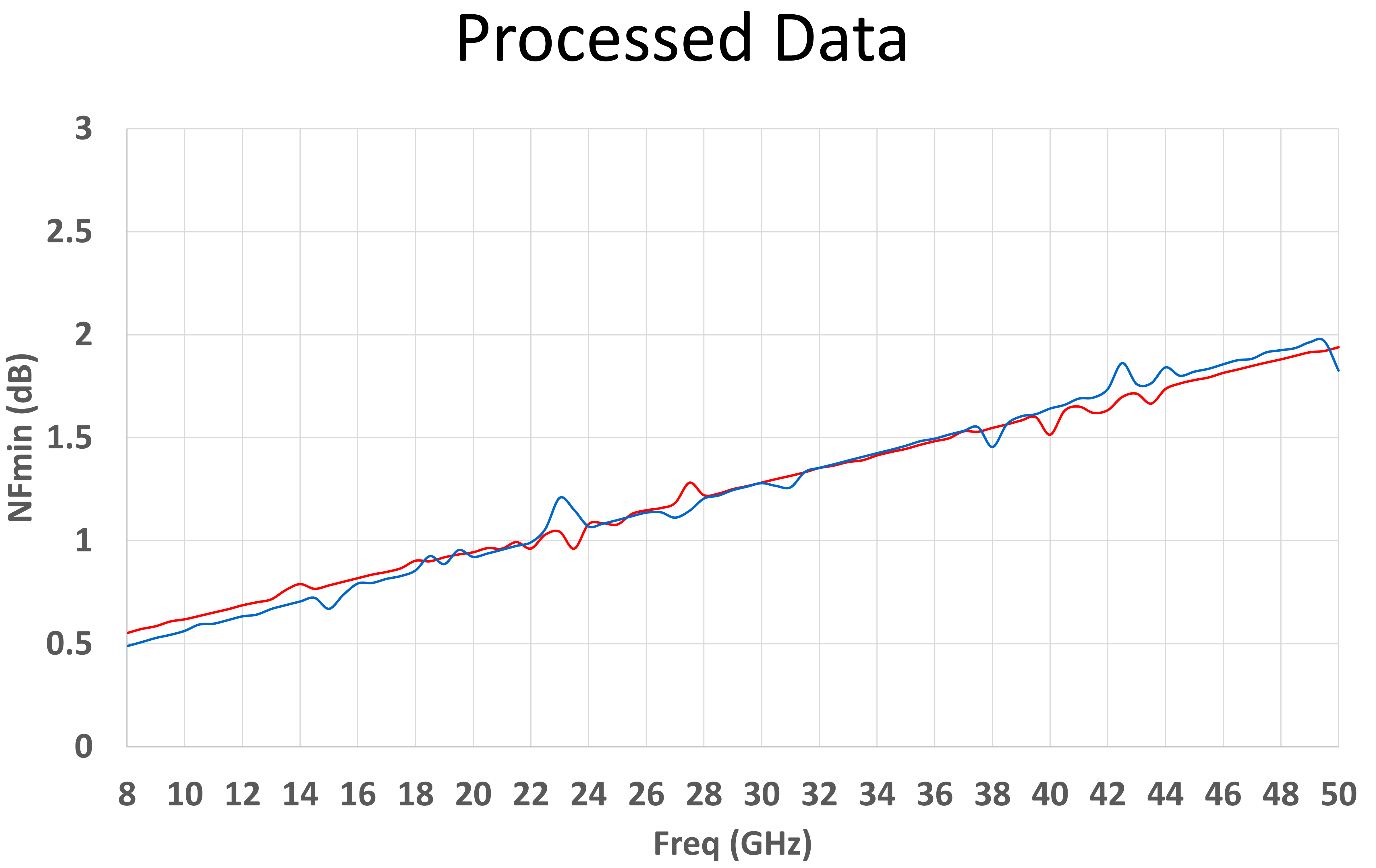
DUT



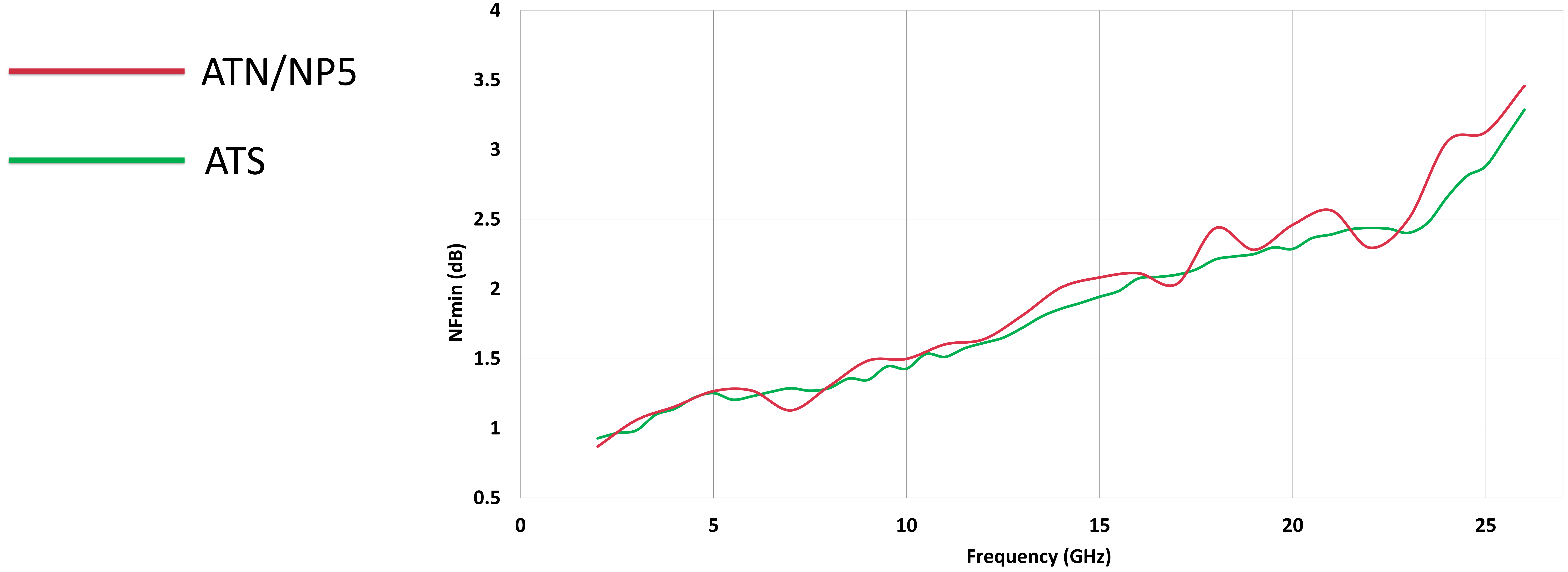
- On wafer Calibration measured over multiple days
- Excellent repeatability
  - Complete tear down and rebuilding setup
  - Multiple coaxial and on-wafer calibrations

Measurements at Different Sites





Benchmark With Legacy ATN System

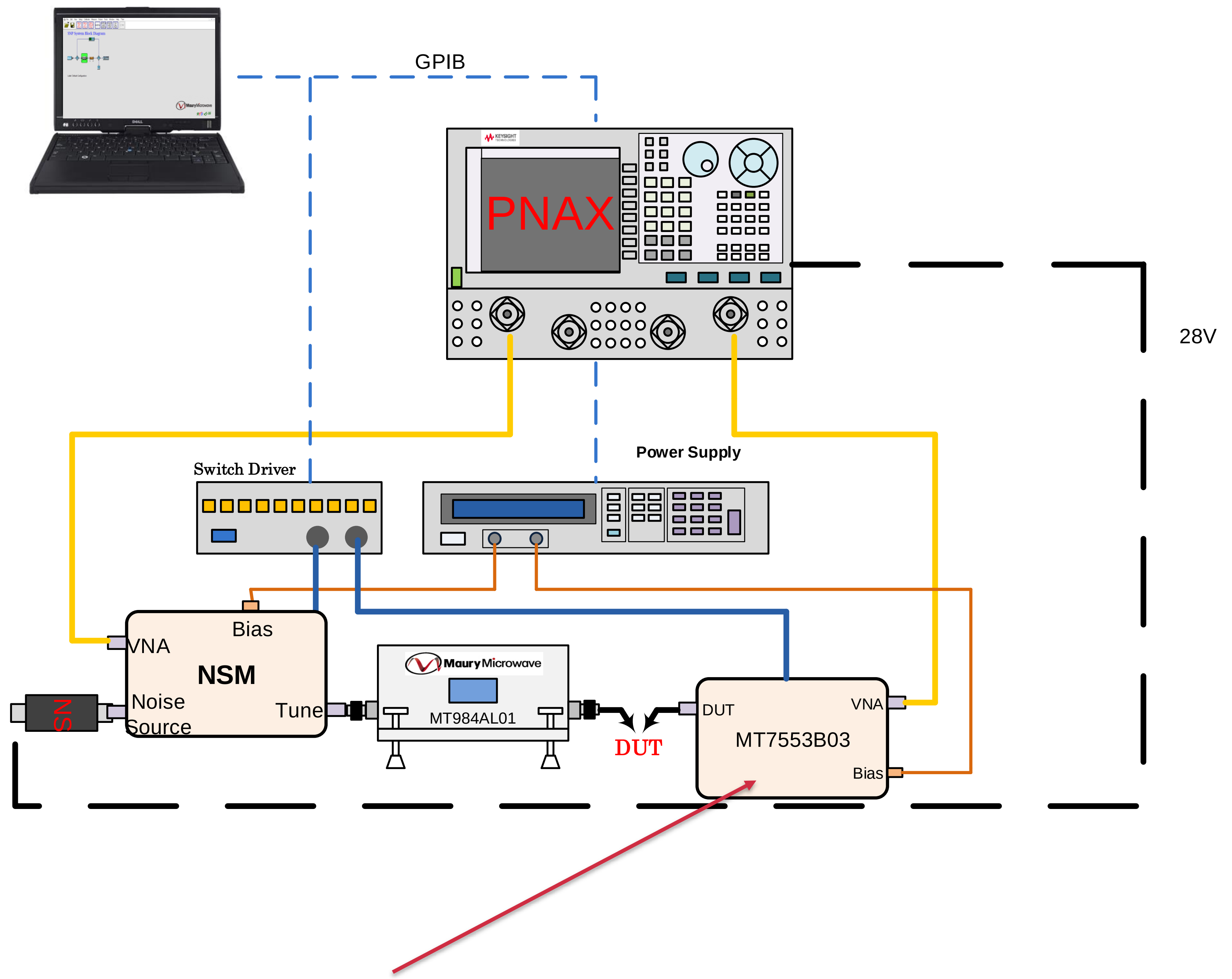


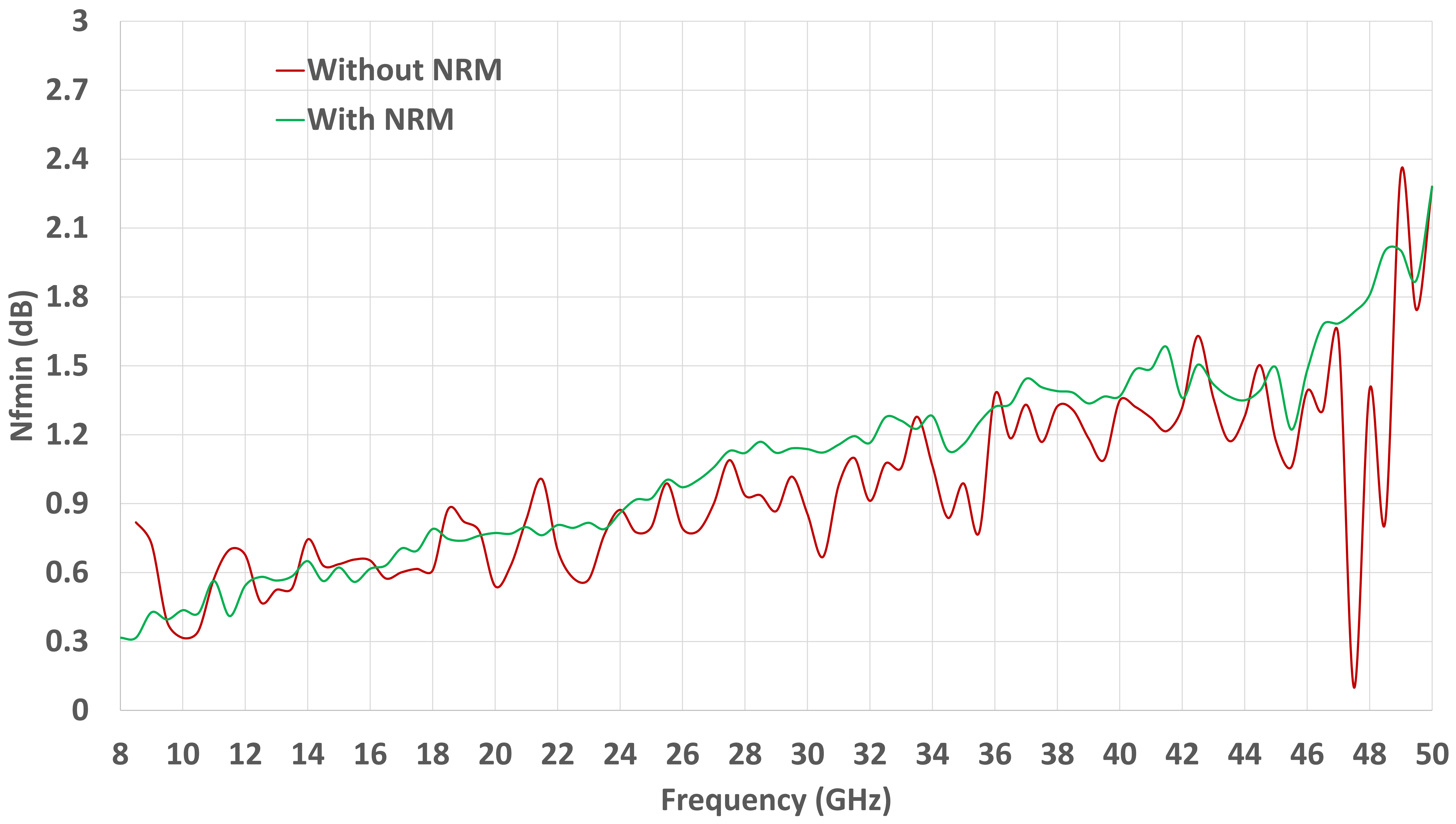
Critical Variables that Affect Noise Parameters Measurements

Noise Receiver Module

With NRM

Without NRM

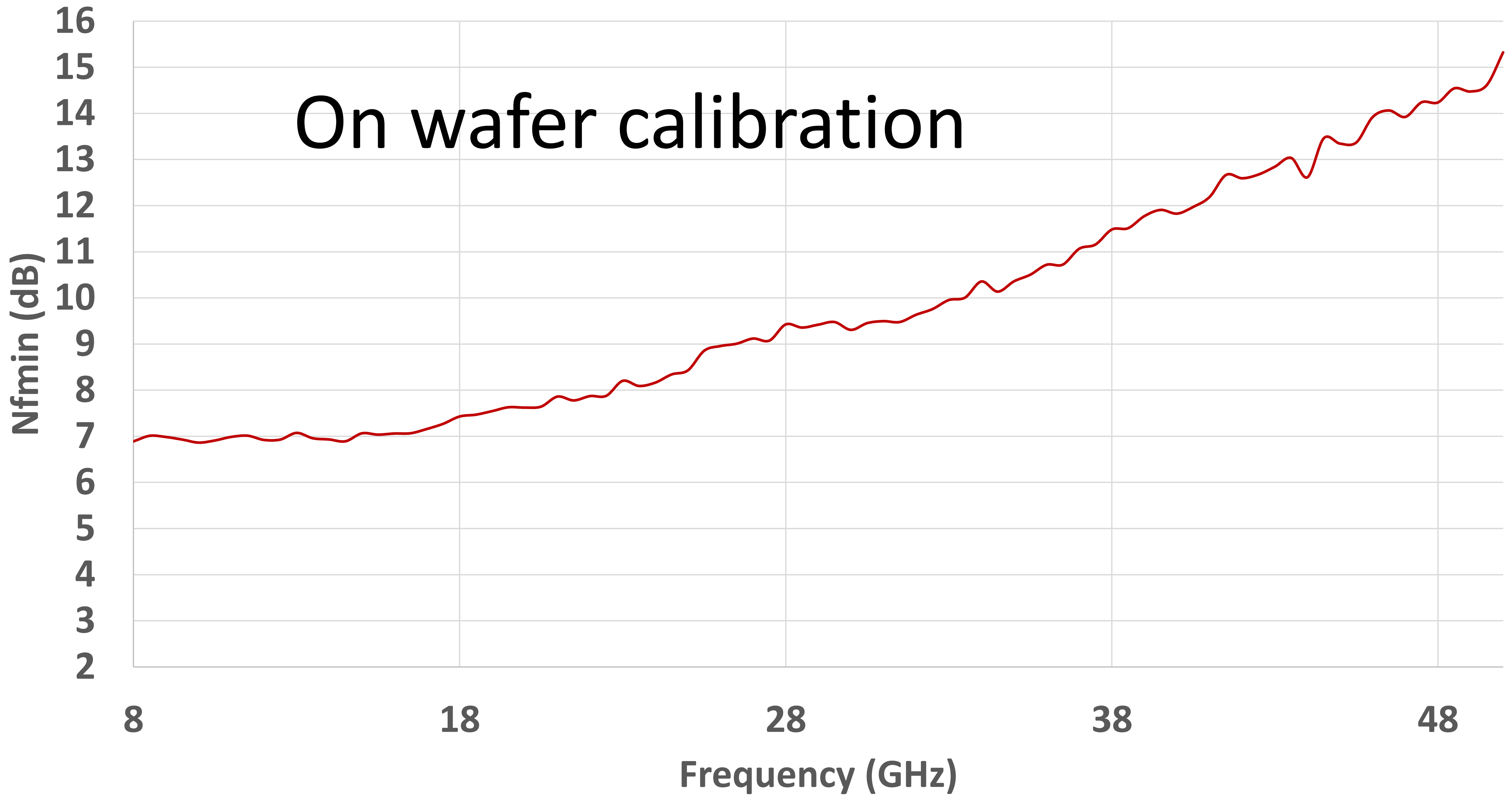




NRM To increase the sensitivity of DUT noise measurement a LNA stage is required.

Maury Microwave Noise Receiver

Model	Freq range	Noise Figure
MT7553B03	0.1-50GHz	10dB Typical 16dB Max



- Hold your solutions providers accountable!
- Published vs actual data comparison

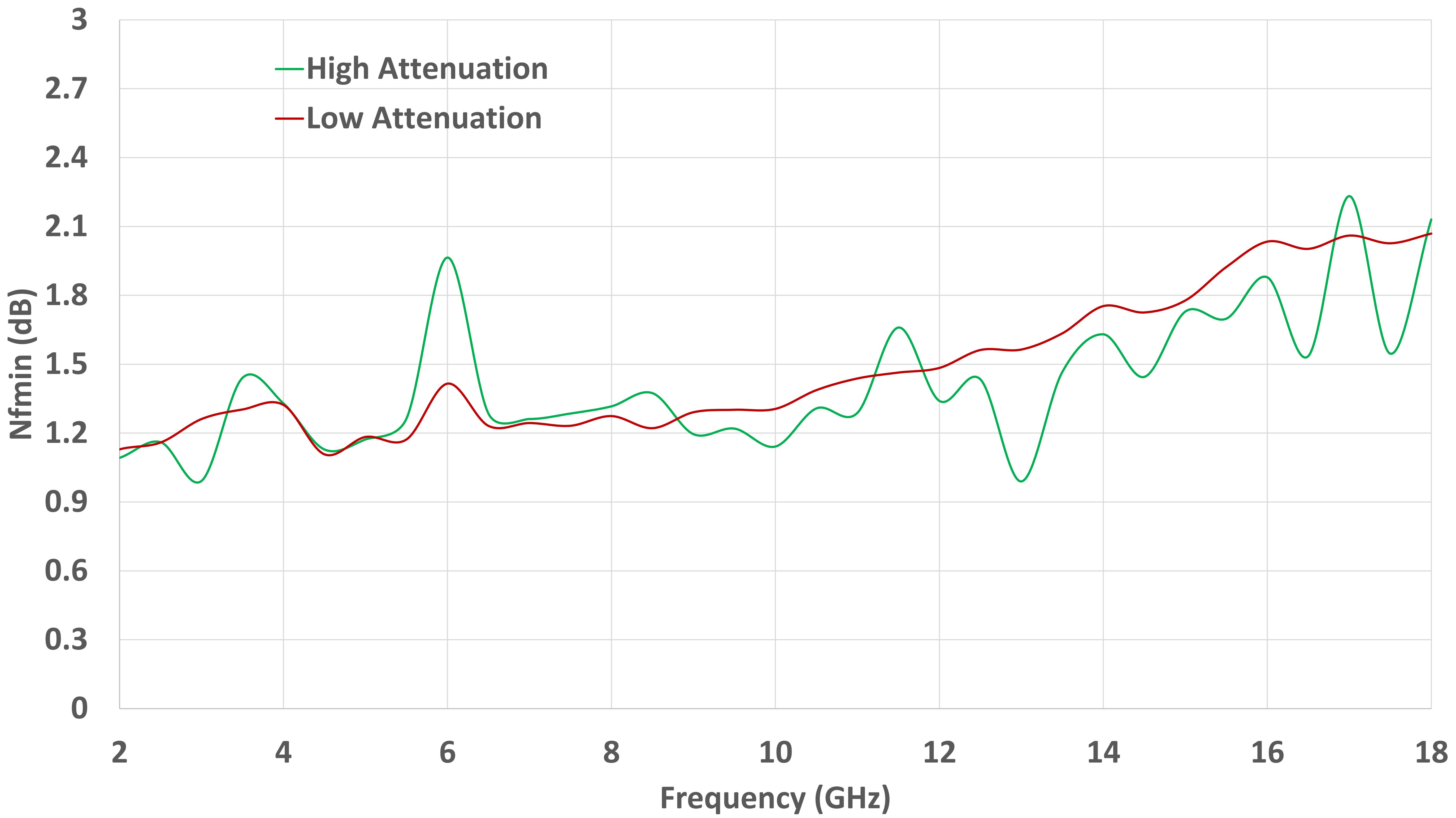
Noise Receiver Attenuation

Measurement Problems

- Too much attenuation
- Too low attenuation
- Receiver overload

High Attenuation

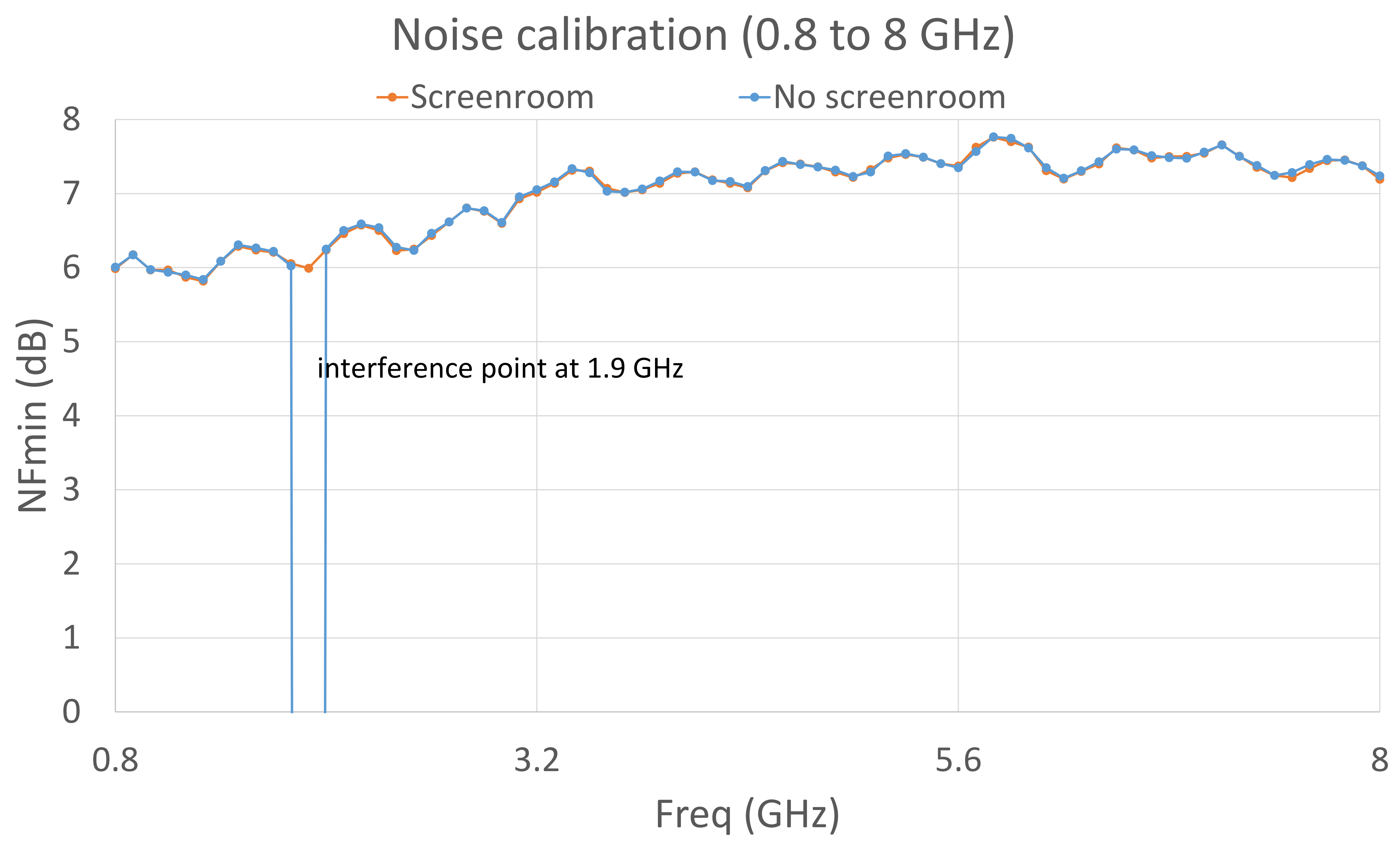
Low Attenuation



- Maury SW has the ability to calibrate at multiple attenuation levels
- Dynamically chooses the <u>right</u> attenuation during DUT measurements

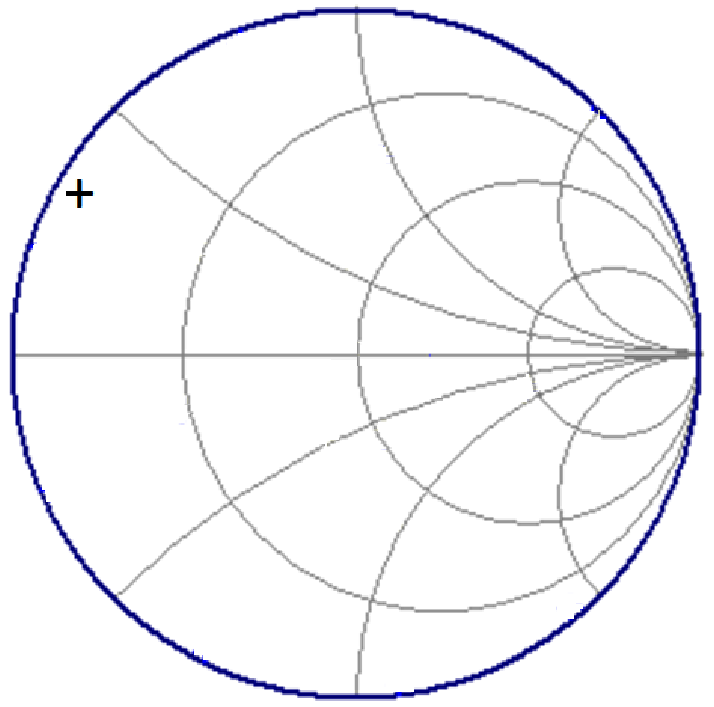
Screened Room (Faraday Cage)

Shields cell phone and wireless signals that can interfere with noise measurements.

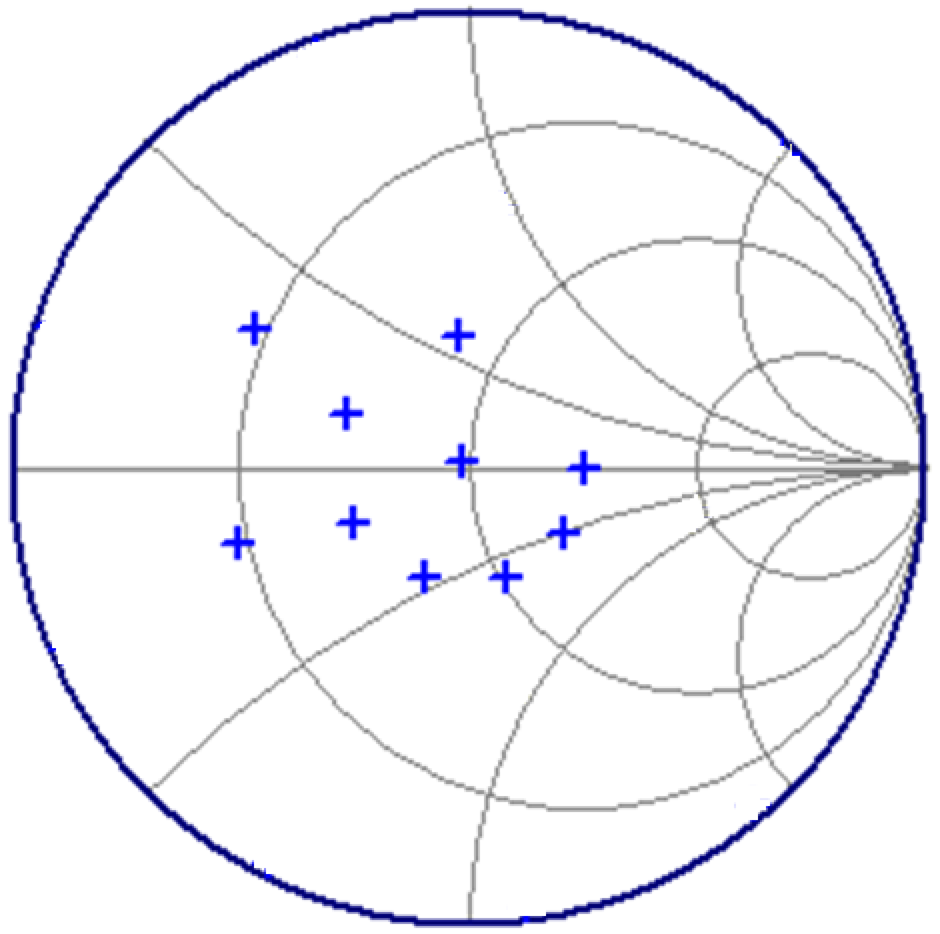


Gamma Source Selection

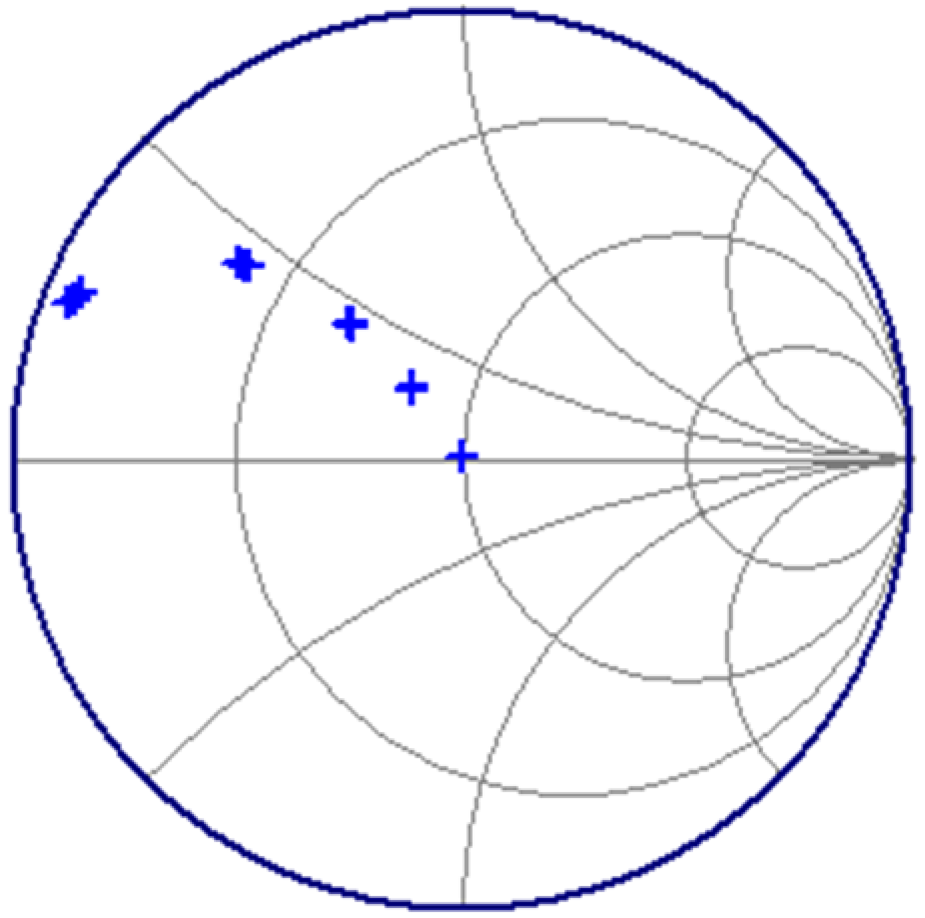
Typical Γ_{OPT} DUT



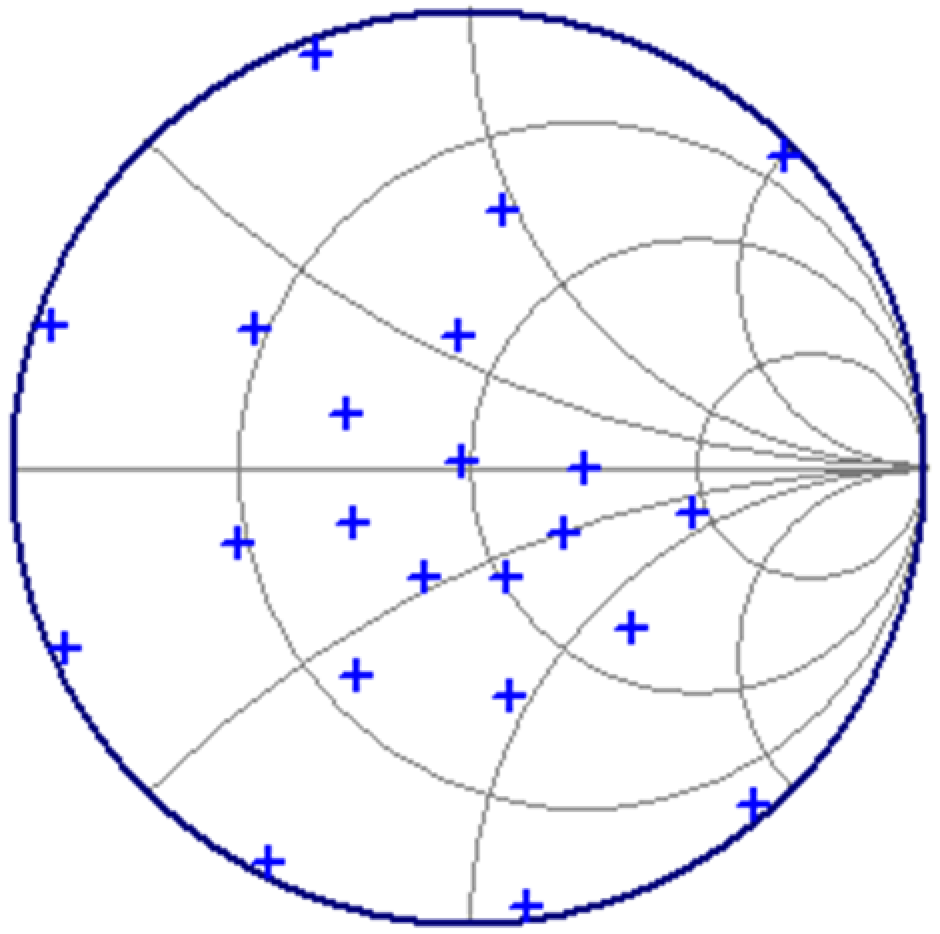
- Need a good Γ_S spread at every frequency
- Need to have the Γ_S spread include high gamma values.



Low Γ_S spread



Bad Γ_S spread

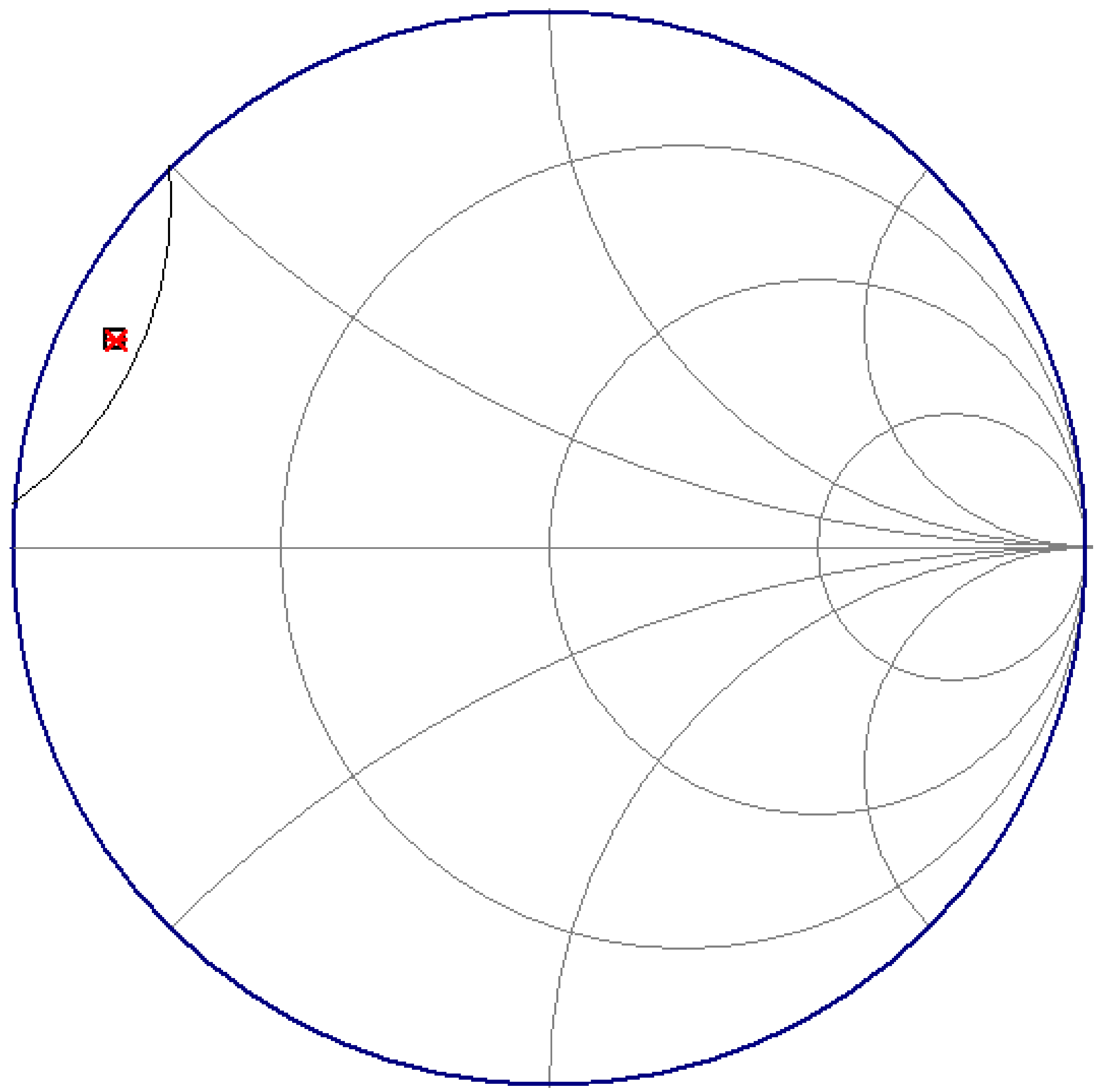


Good Γ_S spread

Oscillation

- At some high-gamma states, oscillation could occur
- MMC Software detects oscillation states and removes them
- Points in the stability circle may not be unstable, they are only **Potential Unstable**, stability also depends on the output load
- **But most high-gamma states are useful –**

  Γ_{OPT} **can be within stability circles**



DUT Γ_{OPT}